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On the Period of Rotation of the Sun as determined by the Spectroscope.

by

Henry Crew

Johns Hopkins University.
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Introduction.

The rotation of the sun includes three elements, viz, its period, its plane, and the longitude of its nodes. For the determination of the last two, astronomers are dependent exclusively upon the telescopic observation of sun spots; the determination of the first is the object of this thesis.

This, too, until very recent years, has been determined only by sun spots; indeed, they were no sooner discovered than Scheiner (1630) used them for this purpose.

Of all methods known, Scheiner's remains the last for obtaining the mean rate of rotation of the ~~mean~~ body of the sun, but its accuracy is greatly impaired by the fact that these spots change form in passing and that their velocity varies with the latitude in a rather uncertain manner;

a fact [illegible] [illegible] [illegible]
by Chandler (1843-1846) [illegible] [illegible]
simple explanation of the discrepancy of
results hitherto obtained. [illegible]
values, those of Chandler and Peters differ
by more than one part in two hundred.

If we accept the method of Prof. Hornstein* of Prague, who proposes to determine the time of the suns rotation from a periodic change of its earths perpendicular, this is but one step left in the method founded on Dr Peters principle.

Following we give,

(1) A short sketch of the work done on this basis.
(2) Description of the apparatus employed.
(3) Discussion of these observations and results.
(4) A list of [illegible] values [illegible] [illegible]
ascertained by this method.

I.

Historical.

Leebeck† records the phenomenon of Dolbear

* Akad. Wien. 1871. June 15
† Pogg. Ann. B. 84 S. 262-264 (1851)

principle as having been first pointed
out by Mr Fizeau.

While on the ice a shelter, having a suitable
frosted surface, [illegible] so that one half of
[illegible] the disc was suddenly lowered.
Doppler* first announced [illegible]
explosion" in 1842; Ballot supported it by
experiment in 1845; and it is generally
[illegible]
[illegible]
[illegible]
in the laboratory, using for the first time
a Lavarts wheel with [illegible]
Doppler explained also [illegible]
by which [illegible] colors of double stars
apparently [illegible]
[illegible]
[illegible]
rays would be introduced from beyond

* Doppler "Ueber das [illegible]

† Fizeau. Ann. Chim. & Phys. 4me Ser. t. 19 (1870)

the other limit of possibility to take their place.

22 lines previously to 1864.

Huggins, Miller, Very, and Lassell have also continued their observations on the, enormous difficulties, requiring much exp[illegible] and extreme caution. Many of their results are little more than qualitative — some even this, since the sign of the motion is in doubt — the probable error being seldom less [illegible]

[illegible] Special care [illegible] the correction [illegible] to obtain [illegible] et, such names as [illegible] of Secchi gave some authority to the opposite [illegible] following.

* Phil. Trans. 1865 p. 539
† Ibid
‡ Huggins. Phil. Mag. S. 4. Vol. 45 p. 14. 1873

But the experiments of Secchi* and Angstrom alone were well founded, because they were the only ones resting on experiment; both Secchi and [illegible] while the displacements indicated by Angstrom, and, therefore, believed that they did not exist.

Angstrom reasons thus. If an electric spark be made to pass between two electrodes, particles of [illegible] which, according to Wheatstone, are about 10 and 90 miles per second. If, now, [illegible] of light, moving with such velocities in [illegible] in the spectrum. Secchi he did not live to be the case, and thence argued the falsity of Doppler's position.

[illegible]

* Angstrom. Pogg. Ann. Bd. 94. S. 152. (1855).

have, and that Angstrom looked for the
line a distinct double!

Van der Willigen* made the fundamental error of thinking that the period as well as the wavelength was altered by the motion of the luminous body: working on this assumption, he obtained his somewhat famous result

The following sentence contains at once his [illegible]

"Au mouvement de la source, pour nous borner à celle-ci, on attribua le pouvoir de changer la réfraction du rayon lumineux.

Ce changement exige une modification de la durée de vibration des molecules dans le rayon incident et de la longeur d'onde normale qui y correspond — c'est-là

* [illegible]
also Annales [illegible] t III f III

point sur l'equel tout le monde est, sans doute, d'accord." (l.c. p. 65.)

In the meantime (1871) it occurred to Göllner*, that [illegible] us with an instrument which is, for the study of light, just what Fizeau's apparatus was for sound. a point on the equator of

[illegible] linear velocity of 1.25 miles per second thus giving a displacement of 1/75 the distance between the D lines, he accordingly mounted his [illegible] by him) upon an equatorial at Dorpat, and [illegible] for the spectral lines.

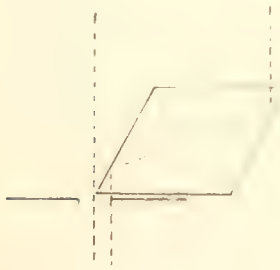
[illegible] the sun upon the slit at the same time.

[illegible] the observations himself, he was delighted a few days later to receive word from his friend,

* [illegible] B. 144 S. 449 (1871)

H. C. Vogel, when he had it in charge the displacement had been observed and measured. The values ranged from 1.62 [illegible] the authors consider little more than [illegible]

[illegible] the center with the edge of the sun, Prof. Hastings [illegible] that the same line [illegible] different places in the two spectra. For this comparison he [illegible] from the limb being twice [illegible] reflected, thus



[illegible] are entitled to any respect, are those [illegible] obtained by making the image of the

† Young. Amer. Jour. Sci. Vol. 12 p. 321 (1876).

travel across the slit of his spectroscope by use of the right ascension [illegible]

[illegible] used were those of the 6", 9" and 11" meters of one of Rutherfurd's 8040-line gratings. But [illegible] the greater definiteness of such one effect it is probable that — definition of this grating in these orders, [illegible] desired — that at that time the best to be had.

Young obtains as the mean of six observations on the linear velocity of a point on the solar equator 1·00 ± ·10 English miles per second; on probable weights, the final result is 1·420 ± ·035 mi. per second.

The value from sun spots on the equator being 1·48 mi. per sec, he suggests that the difference between this value and his own is greater than could be expected from errors of observation and indicates a drifting of the solar surface in the equatorial zone. He says this needs confirmation, and it was with this in view, that the observa-

of the writer were made.

In the meantime, Langley* has, in an incidental way, observed this displacement in a qualitative way, while comparing the [illegible] different parts of the solar disc.

separating the solar and atmospheric lines.

wedge, he gets on the slit of his collimator,

II. Apparatus.

The observations of the writer were made

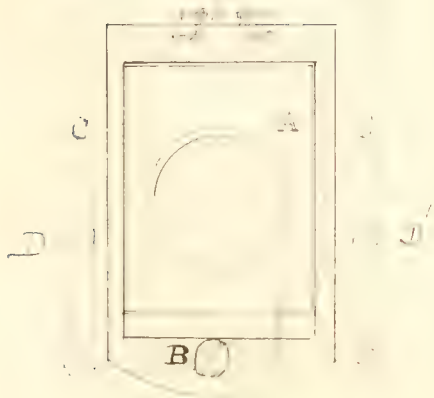
*Langley, Amer. Jour. Sci., Vol. 14 (1877).
also Comptes Rendus (1877).

Hopkins [illegible] an instrument designed by [illegible] an equatorial heliostat with the aid of an auxilliary plane glass mirror.

[illegible] lens of 4½ feet focal length, thus giving an image of 12·5 mm in diameter.

For the displacement of the image upon [illegible]

The lens was screwed into a wooden [illegible] sing[illegible], B, to an [illegible] frame, C, in such a manner that the [illegible] could be [illegible] angle of 5° or 10° about an axis (viz. this bolt, B.) parallel to the [illegible] cal axis.



about the two fixed screws, D and D'

By this means the [illegible] sidewise, either to the right or to the left.

The wooden frame in which the lens was carried at the top two brass slops, as shown in the figure on the preceding page.

In order to bring the eastern limb of the sun upon the slit, we had but to rotate the [illegible] that was by the [illegible] on the fixed brass pin, F; to set the [illegible] on the slit, the ~~other slop was~~ lens was thrown over so that the other slop rested against the brass pin.

There is a adjustment, viz, the rotation of the lens, and the translation of the [illegible] to bring either limb of the sun on the slit, and to [illegible] any slight error of adjustment in the Heliostat.

Both of these adjustments, lens axial as

that of the mirror which reflected the beam from the illuminant upon the comparing desk was made by a system of adjustable mirrors, pulleys and levers, placed convenient to the observer at the eye piece.

Spectroscope.

The collimator and telescope each had an achromatic objective of 6½ inches, made by Mr. Hastings. The focal length of the collimating telescope was 7 feet and 8 inches; that of the observing telescope was 7 feet and 10 inches. Both were attached firmly to a cast iron base. The angle between their optical axes was about 45° and was adjustable through a small range. For the purpose of holding and rotating the grating, this cast iron frame carried the tripod, circle & platform of smaller (14 inch) spectroscope.

The collimator [illegible]

such year, difficult and dangerous.

These lectures evoked such profound interest
of the more physical laboratory, resulting
stupendous and fabulous expenditures, unnecessary &
unreasonable extravagance.

The eye piece of the telescope used with an excellent micrometer drawn by Gaertner
[illegible] eye piece [illegible]

In the focal plane of the eye piece
was fixed a short piece of fine platinum
wire perpendicular. By means of this we
measured the width of the spectrum lines
very accurately and these were
determined. The length of the slit, the
image projected upon the slit of the collimator
by the grating was always made parallel
to the wire, the length [illegible] of which
is [illegible] 14 cm from the eye piece.

The spectrum of the Fe arc was
made [illegible]

x This is the only point in the whole
of the investigation

Easily dividing b_3 and b_4 and the lower component of E.

The following method of determining the angle which the ☉ solar axis makes with the slit of the spectroscope is Prof. Rowland's.

Between the slit and the condensing lens was inserted a prism, mounted in a [illegible] fixture having a vertical axis. This prism was so placed that its axis was coincident with the prolongation of the optical axis of the collimating telescope; it was also fitted with an auxiliary slit in which it rotated, and this was carrying with it the prism.

The prism was placed with its refracting edge perpendicular to the slit.

By [illegible] the mirror of the heliostat was reflected on a fixed slit. The image of this slit was then brought to [illegible]

the slit plate by means of a small lens placed between the prism and the condensing lens. The angle between the image of the slit and that to be measured is another the prism, the one function of the latter being that, which brought to coincidence the vertical threads, the one placed before the slit.

Having obtained the angle of deviation of the two lines with their respective angles of [illegible] to obtain the required angle, viz the angle which the sun's axis makes with the slit

III. Theory, Observations, and, Results.

Let V = velocity of light.

λ = wave length.

v' v'' = relative velocity of two limbs of the sun.*

χ = the heliocentric latitude of the spot

* For more detailed discussion of these angles see p. 19 [illegible]

the slit of the spectroscope is tangent to the sun's limb: call this the "latitude of observation".

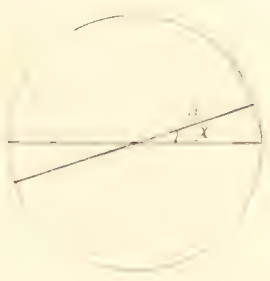
Let Δ = the displacement as measured on the micrometer,

and c = value of one revolution of the micrometer screw in tenth-meters of wavelength.

Then for an observation taken strictly on the [illegible] disc,

$$\lambda = \frac{c}{\quad} \Delta$$

However, in the case of [illegible] setting on the limbs, the slit was allowed a slight encroachment upon the disc of the sun.



If h be half the angle subtended by the [illegible] length of the slit covered by the sun, the correction factor [illegible] this will be $\frac{1}{\cos h}$, barring a negligible error due to the fact that the observation is not taken at the extremities of the slit.

Equator

λ

but in latitude χ. In the most extreme cases this error never amounts to as much as one unit in the second decimal place of $v - v''$.

[illegible] equator moves with a great [illegible]

of this surface drift, the greater [illegible] of empirical formulae [illegible]

Let I = the [illegible]

Carrington's* formula becomes $X = 865' - 165' \sin^{7/4} \chi$

Airy's $X = 862' - 186' \sin^2 \chi$

Jelinek's $X = 1011' - 203' \sin(41°73' - \chi)$

Palmer's $X = \frac{863' - 619' \sin^2 \chi}{\cos \chi}$

[illegible]

* [illegible] p/c. 134, 135. (1st Ed

1, since spots* are rather rare in the region
ill adapted to this, lying, as they do, all
a considerable since the parties sent by the
on April. 5th.

For the present, we follow Young, in
the formula of Faye, which gi-
the following corrected scale—

$$\frac{1}{1 - .216 \sin^2 \chi}$$

which we have tabulated for various latitudes,

$$v' - v' - \frac{c}{\lambda} \left[\frac{\pi}{2} \right]$$

[c varies with the part of the spectrum used]

* the ---- [illegible]

Values of Σ and λ are taken from Expt. [illegible]
of [illegible] and [illegible].

Δ is the difference between two readings of the line, taken under conditions which are practically identical, except that in the one case the eastern, in the other the western, limb of the sun is on the [illegible].

The principal error of the whole experiment is here made in setting on the line.

Two other smaller errors are due to a [illegible] when shifting from "one limb" to the other; [illegible]

[illegible] and was so large that its heat was very intense: as any lateral displacement could [illegible] must have been very small.

The screen was [illegible]

cross-hairs, at various angles and

which the north & south line makes with

the sum (the parallactic angle),

then, $X = p - q - g$

where, p is positive

g is positive after

and g is pos. when (of)

image is to the right of

of the slit.

μ and φ have been tabulated,* so we have only to record φ at the beginning and end of an observation, then remove the prism for the sake of better definition and interpolate for any intermediate time.

With the aid of the following ta[illegible]
of the first [illegible]

4	0·00418	I.	1·49972	18° 00′	0·00405
5	0·00656	D_2	1·50016	19° 20′	·01039
6	[illegible]	[illegible]	·54463	23° 00′	·01112
7	0·01303	5174·0	1·55644	24° 30′	·01644
		171·8	1·55664	25° 30′	[illegible]
		5166·5	1·55708	26° 00′	·01841
				27° 00′	[illegible]
				29° 00′	·02263
				32° 00′	·02718

* For μ see Young's Nat. p. 139
For φ see Loomis' Rec. 384. for Wash
cur[illegible] for 1[illegible] t. = only 2

Observations.

Date	Line observed *	Latitude of observation	no. of obs. of which Δ is mean	Δ	$v' - v''$	no. obs. × $v' - v''$	$(v' - v'' - 2{\cdot}655)^2$
Feb.							
28	5174.0	23°·54	12	·0[illegible]	2·5[illegible]	30660	·010000
28	5174.0	23·62	7	·0887	2·684	18788	·000841
28	b R	23·85	6	·0737	2·248	13488	·165649
28	b R	23·87	8	·0801	2·463	19704	·036864
Mar. 8	5171·8	25°·63	14	·0750	2·351	32914	·092416
"	5171.8	25·48	7	·0850	2·646	19522	·000081
"	5166·5	25·38	8	·0850	2·641	21128	·000196
"	D_1	25·21	7	·0994	2·705	18935	·002500
"	D_1 R	25·07	9	·0979	2·696	24264	·001681
"	D_1 R	24·88	9	·0948	2·619	23571	·001296
"	5174.0 R	24·32	10	·0780	2·437	24370	·047524
Mar. 11	5174.0	27·4[illegible]	6	·0824	2·63[illegible]	[illegible]	[illegible]
"	D_1	27·19	6	·0944	2·637	15822	·000324
12	D_1	26·91	9	·0916	2·560	23040	·009025
"	5174.0	26·88	10	·0860	2·745	27450	·008100
16	D_1	29·28	10	·0865	2·471	24710	[illegible]
"	5174.0	28·67	10	·0856	2·771	27710	[illegible]

* [illegible]

Date	Line	Latitude	no. obs.	Δ	$v' - v''$	no. obs. × $v' - v''$	$(v' - v'' - 2.655)^2$
Mar. 26	D_1	25°28	10	0·1052	2·935	29350	·078400
30	"1474"	33°22	22	·0817	2·760	60720	·011025
30	D_2	32·72	12	·0962	2·910	34920	·057121
30	D_2	32·17	15	·0980	2·970	44550	·099225
June 1	D_1	34·28	10	·0845	2·581	25810	·005476
5	D_2	34·84	10	·0859	2·655	26550	·000000
8	D_1	32·02	10	·0845	2·517	25170	·019044
			237			629268	718988

This gives as the relative velocity of the points on the same meridian, situated at opposite extremities of any diameter, 2·650 ± ·024 English miles per second, a velocity which corresponds to a period of rotation of 23·72 days.

Since writing the above Prof. Young has called my attention to the fact, first suggested by Prof. Peirce, that in such comparisons of results we should employ not the squares but the squares of the [illegible]

In other words, correction must be made for the motion of the earth in its orbit; since this, unlike the rotation of earth on its axis, affects the readings of the two limbs with opposite signs.

Let α = inclination of earth's orbit

ϕ = angular distance of the sun,

then the correction to $v' - v''$ will be

$$a \sin \phi = 18.496 \sin 16'.3 = 0.0862 \text{ mi. per second,}$$

which makes my final value

$$v' - v'' = \text{~~2.9185~~} \quad 2.827 \pm .024 \text{ mi. per sec.}$$

which gives a period of 27.78 days.

I have also introduced this correction into the values of Δ and Δ' which are given in the following pages for [illegible]

Comparison of results.

Observer	Object	Velocity in miles per sec.	Period
Spoerer	Sun spots	2·497	25·23 days
Carrington	"	[illegible]	25·38 "
Vogel	Spectroscope	2·73	16·7 "
Young	"	[illegible]	[illegible] "
Crew		2·827 ± .024	22·28 "
Hornstein	Periodic change in the inequalities of	2·46	28·64 "

Discussion of Results.

Of my result the same must be said as of Young's and Vogel's, that the difference between the result obtained from the observation of sun spots in Carrington's case can be accounted for by the rotation of the solar atmosphere. The evidence we have [illegible] that this difference must be attributed to a peculiar law of rotation of the upper layers of the photosphere

over the lower ones, six months are [illegible]
Sunspots to [illegible] the same spots are formed.

Indeed "velocity of rotation" has no meaning
nothing unless we define the "motion of the
sun" under discussion.

This drifting of the upper layers over the lower
at any one point is not to be confounded with
that expressed in the preceding formula of
Faye.

$$X = 862' - 186' \sin^2 \chi$$

where X is the daily angular motion, and
χ the latitude of the point.

The motion of the spots, upon the observations
of which this formula is based, is determined,
many obs one hour while that indicated by the dis-
placement of the lines of [illegible] different ones
Now it is not to be [illegible] that
Young's value of $v' - v''$ and my own indicates a great
variation from the [illegible] of the
Sun spots between the mean latitude

(about 7°) of his observations and that of mine about 27°!

Accurate observations, of all possible kinds, are needed to determine for (here upper layers a law comes (if such exist) corresponding to that which Carrington has determined for the lower layers.

Such an empirical speculation may be useful in the final solution of the great problem* [illegible] the sun's equator.

With reference to the large probable error attaching to all these observations, may it not be that, during the period of one observation, say half an hour, the local solar disturbances are of sufficient [illegible] to affect the readings of the micrometer?

A comparison (including mean and probable error) of [illegible]

* For the hypothesis of Herschel, Spoerer, and Faye with [illegible]

a similar solar line might answer this question.

Taking the values of $\nu' \nu''$, obtained from different lines, we have,

From 5174·0 line ("b₄")	2·032 ± ·[illegible]
" D	2·[illegible] ± ·[illegible]
"1474" line	2·760 ± ·075

It is possible that these results have physical significance, since here the difference would seem to warrant; but further observations

Each of line alone presented making a series of [illegible] this might give an extraordinary velocity.

II. Separation of Atmospheric and Solar Lines.

[illegible] that that given above. At the proper time of year, this method leaves little to be desired, except for very faint lines.

The one precaution necessary is an [illegible]

No more beautiful confirmation of Doppler's principle can be found than that afforded by the motion of a line, say, in the "b group" of the 4th order, with reference to a line of the "3 group" of the 5th order. [illegible] needed, or even possible, since [illegible] might be made on the motion of a [illegible]

line of one order with reference to a solar line of another.

Cornu has separated the solar lines of the A, [illegible] & group.

We have examined the portion of Rowland's map between wave lengths 5050. and 5316.9 ("474"), and find the following lines to be solar in their origin:

[The wave lengths given are taken from the map. Lines marked "d" are double.]

5050.2	5075.0	5091.1	5114.7	5129.9	5145.7
51.9	75.5	94.7	15.7	30.7 d	46.4
52.4	76.6	97.2	16.8	31.7	46.8
54.9	79.4 d	97.7	17.0	32.0	47.4
57.1	80.2 d	98.9	18.2	32.9	47.8
57.8	80.8	99.5	19.4	33.9	48.4
58.3	81.4	5100.2	20.7	37.4	48.6
60.4	82.6	03.2	21.9	37.7	51.5
64.9	83.7	04.4 d	23.0	39.7 d	52.2
65.4 d	84.4	04.7	23.5	41.0	52.4
66.3	85.8	05.8	24.0	41.6	53.6
67.4	86.5	07.8 d	24.9	42.0	53.7
68.0	87.4	08.7	25.4 d	42.8	54.3
69.0	87.7	09.9	26.5	43.1 d	54.6
71.7	88.5	10.7	27.7	44.0	55.4
72.5 d	88.8	11.0	29.4	44.7	56.0
73.0 d	89.4	13.6 d	29.7	45.4	56.9

51 57.4		51 96.7	d	52 24.6		52 55.3	b_4	53 96.7	
57.9		97.5		24.8		55.9		95.6	
58.1		97.8		25.2		57.2		96.0	
58.8		98.2		25.8		57.9		96.9	
59.3		99.0		26.8		60.7		97.7	
62.6	Fe	52 00.6	d	27.2		61.9		98.3	
64.9		01.4		27.4		62.4		98.5	
65.4		02.6	Fe	28.3		63.2		98.7	
65.7		04.8	Fe	28.6		63.6		99.1	
66.7		06.0		30.2		64.1		53 00.3	
67.6	d b_4	06.3		30.4		64.4	d	00.7	
68.9		08.2		33.2		65.1		01.0	
69.2	d b_3	08.8	d	34.9		65.4		01.2	
71.7		10.2		35.6		65.8	d	02.6	
71.9		10.7		35.7	d	66.2		04.3	d
73.0	b_2	11.1		36.4	d	66.8		06.1	
74.1		11.5		37.6		67.5		07.7	
76.9		11.8		38.8		68.7	d	08.8	
77.6	d	12.6		39.2		69.7	E	11.0	
79.1		12.9		40.1		70.6	E	13.1	
79.3		13.7		40.7		71.4	d	13.8	
80.4		14.2		41.2		72.3	d	15.3	
81.7		14.4		42.4		73.6	d	17.0	"1474"
82.1		14.9		42.7		74.5			
84.0	b_1	15.4		43.4		74.8			
84.8	d	15.8		43.6		75.4	triple		
86.2		16.6		44.1		76.1	d		
86.8	d	16.7		47.0		80.3	d		
88.2		17.7		47.3		80.9			
89.0	d	18.2		47.5		82.0			
91.7	Fe	18.4		47.7		82.7			
92.2		20.0		48.2		83.9			
92.6	Fe	20.4	d	48.5		84.3			
93.2		21.3	d	49.4		84.7	d(?)		
93.7		22.0		50.6		85.4			
94.3		22.8	d	50.9		88.7			
95.2	Fe	23.5		52.3	d	92.7			
95.7		23.8		54.4		93.3	d		
96.3		24.4		54.7		94.2			

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